

**Modelling Service Life and Life-Cycle Cost of
Steel-Reinforced Concrete**

**Report from the NIST/ACI/ASTM Workshop held in
Gaithersburg, MD on November 9-10, 1998**

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Building and Fire Research Laboratory
Gaithersburg, Maryland 20899



United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

NISTIR 6327

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May 1999

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United States Department of Commerce

William M. Daley, *Secretary*

Technology Administration

Gary R. Bachula, *Acting Under Secretary for Technology*

National Institute of Standards and Technology

Ray Kammer, *Director*

APPENDIX 1

Steering Committee and Workshop Participants

Steering Committee

Geoff Frohnsdorff	Building and Fire Research Laboratory, NIST
Shuaib Ahmad	American Concrete Institute
Emmanuel Attiogbe	Master Builders, Inc.
Neal Berke	W.R. Grace Company
Dan Falconer	American Concrete Institute
Doug Hooton	University of Toronto
Paul Johal	Prestressed/Precast Concrete Institute
Colin Lobo	National Ready Mixed Concrete Association

Workshop Participants

Shuaib Ahmad	American Concrete Institute
Antonio Aldekiewicz	W.R. Grace Company
Stephen Amey	Master Builders Inc.
Emmanuel Attiogbe	Master Builders Inc.
Dale Bentz	Building and Fire Research Laboratory, NIST
Evan Bentz	University of Toronto, Canada
Neal Berke	W.R. Grace Company
Nick Carino	Building and Fire Research Laboratory, NIST
Marta Castellote	Eduardo Torroja Inst. of Construction Sciences, Spain
Jim Clifton	Building and Fire Research Laboratory, NIST
Mark Ehlen	Building and Fire Research Laboratory, NIST
Geoff Frohnsdorff	Building and Fire Research Laboratory, NIST
Ed Garboczi	Building and Fire Research Laboratory, NIST
David Gustafson	Concrete Reinforcing Steel Institute
Terry Holland	Silica Fume Association; and Chairman, ACI / TAC

Workshop Participants (continued)

Doug Hooton	U. of Toronto, Canada
Paul Johal	Precast/Prestressed Concrete Institute
Paul Kelley	Simpson, Gumpertz and Heger
Alistair MacDonald	W.R. Grace Company
Bryan Magee	Purdue University
Jaques Marchand	Laval University, Canada
Nick Martys	Building and Fire Research Laboratory, NIST
Matthew Miltenberger	Master Builders Inc.
George Muste	National Ready Mixed Concrete Association
Ted Neff	Consultant
Lars-Olaf Nilsson	Chalmers University, Sweden
Charles Nmai	Master Builders Inc.
Jan Olek	Purdue University
Ed O'Neil	U.S. Army Corps of Engineers / WES
Michael Ortlieb	Carl Walker, Inc.
Clauss Germann Petersen	Germann Instruments, Denmark
Mark Postma	Carl Walker, Inc.
Ervin Poulsen	AEC, Denmark
Alberto Sagüés	South Florida University
Michael Sprinkel	Virginia Transportation Research Council
Michael Thomas	University of Toronto, Canada
Paul Tournay	Grace Construction Products
David Trejo	University of Texas
Alex Vaysburd	Structural Preservation Systems
Paul Virmani	Federal Highway Administration

APPENDIX 2

THE NIST / ACI / ASTM WORKSHOP ON MODELS FOR PREDICTING THE SERVICE LIFE AND LIFE-CYCLE COST OF STEEL-REINFORCED CONCRETE

AGENDA

DAY 1 (November 9)

7:30 Continental Breakfast

Plenary Session 1

8:00 Welcome and review of the workshop goals Geoffrey Frohnsdorff, BFRL/NIST

RILEM Technical Committee TMC, Testing and Modelling Chloride Penetration in Concrete – Goals and Plans

8:10 Marta Castellote, Eduardo Torroja Institute of Construction Sciences, Spain

Presentations on Models for Predicting Service Life and Life-Cycle Cost of Steel-Reinforced Concrete

8:40 Alberto Sagues, University of South Florida

9:10 Lars-Olof Nilsson, Chalmers University, Sweden

9:40 Ervin Poulsen, AEC, Denmark

10:10 COFFEE BREAK

10:25 Michael Thomas, University of Toronto, Canada

10:55 Jacques Marchand, Laval University, Canada

11:25 Paul Tourney, W.R. Grace Company

11:55 Matthew Miltenberger, MasterBuilders Company

12:25 BUFFET LUNCH

1:25 Dale Bentz, Building Materials Division, BFRL/NIST

1:55 Mark Ehlen, Office of Applied Economics, BFRL/NIST

Working Group Activities

2:25 Instructions to Working Groups

2:40

BREAK

Working Group Session 1

3:00 Working Group discussions (WG 1 through WG 4)

5:30 Adjournment

6:30

DINNER

8:00 Meeting of Steering Committee with Working Group Chairs/Co-Chairs

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DAY 2 (November 10, 1998)

7:30 Continental Breakfast

Plenary Session 2

8:00 Reports from chairs of WGs in Working Group Session 1

Working Group Session 2

9:00 Working Group discussions (WG 5 through 8)

10:30

COFFEE AVAILABLE

12:00

BUFFET LUNCH

Plenary Session 3

12:45 Reports from chairs of WGs in Working Group Session 2 Terry Holland, Consultant

2:40 Final discussion and recommendations for action Terry Holland, Consultant

3:00 Adjournment

APPENDIX 3**Working Group Assignments****Working Group 1**

Doug Hooton, Chair
Shuaib Ahmad, Co-Chair
Nick Martys, Recorder
Mark Ehlen
Terry Holland
Alistair MacDonald
Jacques Marchand
Lars-Olof Nilsson
Charles Nmai
Ervin Poulsen

Working Group 2

Albert Sagues, Chair
Neal Berke, Co-Chair
Dale Bentz, Recorder
Stephen Amey
Evan Bentz
Paul Kelley
George Muste
Michael Ortlieb
Mike Sprinkel
David Trejo

Working Group 3

Jan Olek, Chair
Paul Johal, Co-Chair
Ed Garboczi, Recorder
Marta Castellote
Geoff Frohnsdorff
Matthew Miltenberger
Clauss Germann Petersen
Mark Postma
Paul Tourney
Alex Vaysburd

Working Group 4

Mike Thomas, Chair
Emmanuel Attiogbe, Co-Chair
Nick Carino, Recorder
Anthony Aldykiewicz
James Clifton
Dave Gustafson
Bryan Magee
Ted Neff
Ed O'Neill
Paul Virmani

**Working Group Assignments
(continued)****Working Group 5**

Doug Hooton, Chair
Shuaib Ahmad, Co-Chair
Nick Martys, Recorder
James Clifton
Paul Kelley
Alistair MacDonald
Matthew Miltenberger
Ted Neff
Lars-Olof Nilsson
Clauss Germann Petersen
David Trejo

Working Group 6

Alberto Sagues, Chair
Neal Berke, Co-Chair
Dale Bentz, Recorder
Marta Casellote
Geoff Frohnsdorff
Bryan Magee
Charles Nmai
Mark Postma
Alex Vaysburd

Working Group 7

Jan Olek, Chair
Paul Johal, Co-Chair
Ed Garboczi, Recorder
Anthony Aldykiewicz
Stephen Amey
Dave Gustafson
Jacques Marchand
Ed O'Neill
Ervin Poulsen
Paul Virmani

Working Group 8

Mike Thomas, Chair
Emmanuel Attiogbe, Co-Chair
Nick Carino, Recorder
Evan Bentz
Mark Ehlen
Terry Holland
George Muste
Michael Ortlieb
Mike Sprinkel
Paul Tourney

APPENDIX 4

New, Formable, Corrosion-Improved, Low-Carbon Steels for Concrete

(An abstract provided by Gareth Thomas, University of California, Berkeley and San Diego, who was unable to attend the workshop)

Reinforced concrete structures are an integral part of everyday life. Inadequacies in the overall design perspectives of reinforced concrete structures, which pay insufficient attention to durability – mainly corrosion resistance – result in many structures deteriorating well before their life expectancy. The result is enormous costs for repair and rehabilitation of highway structures due to corrosion damage, amounting to billions of dollars.

An important challenge is to involve the principles of Materials Science and Engineering, to design by microstructural control, through processing, steels which are economically attractive, and which provide superior mechanical and corrosion resistance properties. This paper describes such an approach using the principles of low carbon dual phase steel (DFM).

In this system, the microstructure is designed to avoid carbide particles which in the presence of ferrite, or other phases, localizes the anodic-cathodic coupling in a galvanic situation. Since all structural steels in current use have carbides in their structure, they are all susceptible to galvanic attack. Thus, the design of steels with ferrite-martensite structures (DFM), in the absence of carbides, allows us to easily attain mechanical property requirements for reinforcements, with greatly improved corrosion resistance.

In all cases, the DFM steels show superior properties, are easily welded and show excellent formability, e.g., in wire drawing, corrosion results show that in the long-term weight loss data, a smooth bar showed no detectable corrosion after one year, and the short-term tests in chloride solutions, dramatically shows the superior corrosion resistance of DFM to A-615 rebars; the latter are almost completely destroyed after three weeks exposure.

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- The original paper, by Gareth Thomas of the University of California and David Trejo of Michigan State University, was presented at the Workshop on Materials for the Infrastructure, La Jolla, California, April 1-3, 1998. The workshop was sponsored by the Institute for Mechanics and Materials (IMM), University of California, San Diego (UCSD), and the National Science Foundation. The workshop proceedings were published as Report No. 98-1 from the IMM, UCSD, 9500 Gilman drive, Dept. 0404, La Jolla, CA, 92093-0404.

APPENDIX 5

Loading Effect on Corrosion of Reinforcing Steel

(Abstract provided by Surendra Shah of Northwestern University who was unable to attend the workshop)

A great deal of research on corrosion of reinforcing steel in concrete has been done regarding material properties, mix proportions, corrosion protection, repair and retrofitting, as well as service life prediction. Limited work has been done clearly illustrating the mutual interaction among loading, cracking, and corrosion damage. The objective of the present research is to investigate this interaction. Reinforced concrete beams, (10 x 10 x 110) cm, were prepared and subjected to different levels of flexural loading: (0, 45, 60, and 75) % of the ultimate load. They were also exposed to a laboratory environment with ponding and wetting / drying cycling at room temperature. Half cell potential and galvanic current measurements were taken daily to monitor the corrosion of the reinforcing steel. After corrosion initiation, external current was applied to the beams to accelerate the corrosion. The beam deflections and crack characteristics were recorded during the entire test. The remaining loading capacity of the beams was evaluated at the end of the experiment. The results indicate that loading has a significant effect on the corrosion rate of reinforcing steel. Corrosion increases beam deflection. Loading level has a considerable effect on the initiation of corrosion, but the effect reduces after corrosion initiation. The beams under load had much higher corrosion rates than those which had been preloaded and then unloaded. The present research may provide another look into current service life predictions of concrete.

* The abstract was of a paper submitted to the ACI Spring Convention in Chicago in March 1999. The authors are Sang-chun Yoon, Hyung-rae Kim, Kejin Wang, Jason Weiss, and Surendra P. Shah, NSF Center for Advanced Cement-Based Materials, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208.

APPENDIX 6

Chloride Penetration into Concrete with Light Weight Aggregates

(Abstract provided by Magne Maage of Selmer ASA, Trondheim,
who was unable to attend the workshop) *

The experimental work started as a part of the Lightcon project with the objective of studying chloride ingress into practical LWA concretes depending on many variables as well as giving input to the model for service life prediction developed in the same project. Eight concretes have been tested, two by two were identical except that half of the cement content was replaced by slag in one of the two. All mixes had 5 % to 10 % silica fume by weight of cement plus slag. The most important variables were: (1) curing time before exposure, (2) curing time (20, 65 and 95) °C, (3) exposure temperature (5, 20 and 35) °C, (4) exposure time, (5) type of exposure (submerged, splash, spray), (6) salt concentration in exposure water (1, 4 and 10) %, (7) type of binder (OPC and OPC + slag).

The most important conclusion was that the results fitted very well to the hypothesis for service life prediction. Additionally, the following main conclusions may be mentioned:

Surface chloride content, C_s , is the environmental load and it increases with exposure time during the first years, reduces with increased curing time and introduction of slag, and independent / inconsistent correlation to curing and exposure temperature.

The achieved diffusion coefficient, D_i , is independent of curing and exposure temperature, decreases with exposure time and introduction of slag.

The parameter, α , expresses the time dependency of D_i with exposure time; α is independent of curing time, curing and exposure temperature, and increase somewhat with increased salt concentration in the exposure water and introduction of slag.

* This abstract is from a draft report by M. Maage, S. Helland, and J.E. Carlsen, Chloride Penetration into Concrete with Light Weight Aggregates, Report 3.X, SINTEF, Trondheim, Norway, scheduled for publication at the end of 1998.